NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Blade Testing Trends

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Overview

- **Test Capabilities and Methodology**
  - Facilities and Equipment
  - Methods and Expertise.
- **Blade and Testing Trends**
  - Historical Trends
  - Commercialized Hardware.
- **Recent Testing Activities**
  - Biaxial Testing Methods.

National Wind Technology Center (NWTC)

- **NREL's National Wind Technology Center (NWTC)**
  - Located near Boulder, Colorado
  - Provides testing infrastructure and services for research and development (R&D) and industry support.
- **Field Testing**
  - Small to megawatt-scale turbines (more than 10 MW installed)
  - Demonstrates advances in control systems and innovative technologies.
- **Drivetrain Testing**
  - 225-kilowatt (kW), 2.5- and 5-MW dynamometers
  - Controllable grid interface (CGI) for simulating faults, low-voltage ride-through, reactive power tests.
- **Blade Testing**
  - Three test facilities, up to 50-meter (m) blades
  - Wind and water.

Photo by Dennis Schroeder, NREL 19008

Photo by Dennis Schroeder, NREL 28237

National Wind Technology Center (NWTC)

- **251 and A60 Test Facilities**
  - Test stand capacity = 1.3 MN-m
    - Up to 19-m blades
  - 100- and 490-kN load frames.
- **Structural Testing Laboratory (STL) Highbay**
  - Test stand capacity = 16.3 MN-m
    - Up to 50-m blades.
- **On-Site Heavy Equipment**
  - 75T Shuttlelift
  - 15T Boom truck
  - 10T Telehandler
  - Aerial lifts up to 40-m heights.


Photo by L. Fingersh, NREL 15005


Photo by S. Hughes, NREL 14707

Wind Technology Testing Center (WTTC)

Photo by D. Berry, NREL 19939

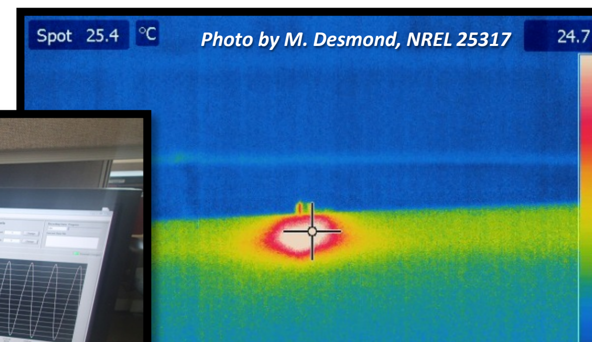

Photo by N. Post, NREL

- **Located in Boston, MA**
- **Operated by Massachusetts Clean Energy Center (MassCEC)**
  - Supported by NREL
    - Test personnel and expertise
    - Data acquisition and test equipment deployment.
- **3 Indoor Test Cells**
  - Test stand capacity = 84 MN-m
  - Up to 90-m blades.

National Wind Technology Center (NWTC)

- **Ethercat Data Acquisition System (EDAS)**
  - Distributed and synchronized Ethercat-based hardware from National Instruments
  - Validated and deployed at NWTC and WTTC for accredited testing
  - NREL custom developed software
    - Real-time peak-valley processing
    - Alarm interlocks.
  - Capability for third-party equipment integration.

- **Additional Capabilities**
  - Acoustic emission (SHM)
  - Thermal imaging (NDE/SHM)
  - Laser tracker system (NDE).



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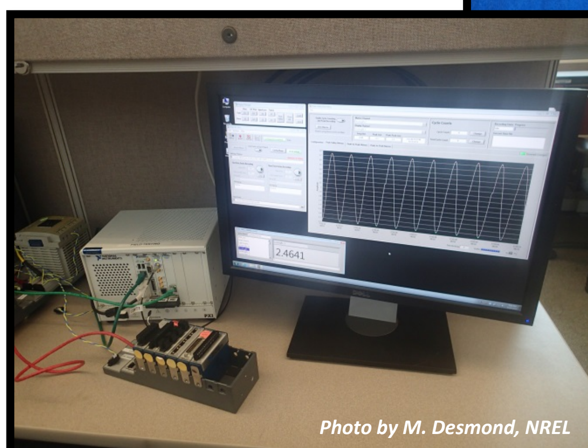

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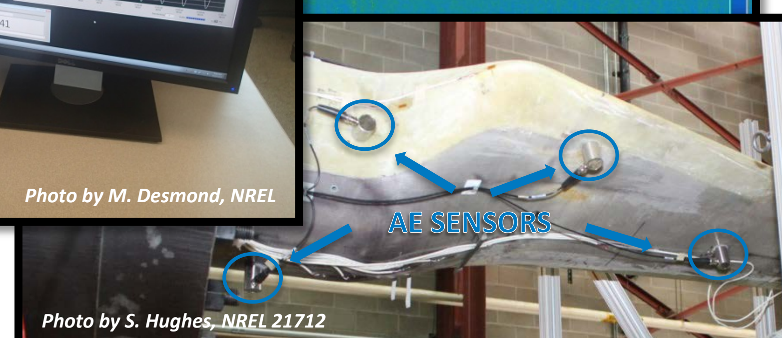

Photo by S. Hughes, NREL 21712

NWTC

- A2LA/ISO 17025-accredited for full-scale wind turbine blade testing to IEC 61400-23 standard
- Years of testing experience = 30+
- Blade tests conducted = 150+.

IEC

ACCREDITED

IEC 61400-23

Edition 1.0 2014-04

INTERNATIONAL STANDARD

Illustration by A2LA and IEC

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Test Methodology

- **Typical Test Sequence**
  - Property/modal testing
  - Static testing
  - Fatigue testing
  - Post-fatigue static.

- **Property Testing**
  - As-built weight, CG
  - Mass/stiffness distributions.
- **Modal Testing**
  - Vibration frequencies
  - Damping estimates
  - Mode shapes
  - Excitation methods include impact hammer, step relaxation, shaker, and OMA.

Test Methodology

- **Static Testing**
  - Tests the ability of the blade to withstand design load cases
  - Load application through quasi-static methods
    - Winches, actuators, cranes, and ballast weights.
  - Load applied with accuracy through winch controller
    - Simultaneous and independent control of each winch
    - Precise load matching via real-time load cell feedback
    - Safety interlocks to minimize overload situations.

Photo by Scott Hughes, NREL 14708

Photo by Dave Snowberg, NREL 20438

Test Methodology

Photo by Lee Jay Fingersh, NREL 16269

- **Fatigue Testing**
  - Lifetime verifications address durability and reliability
  - Twenty-year blade life on the order of 1 billion cycles in the field
  - Laboratory loads are increased to accelerate test and complete damage equivalent fatigue in millions of cycles
  - Current methods
    - Forced displacement
    - Inertial resonant.
  - Methods in development
    - Base excitation
    - Forced resonant hybrid.

Why Test Blades?

- **Testing is a certification requirement**
  - Blade reliability identified as significant operation and maintenance (O&M) cost
  - Identify manufacturing weaknesses
  - Minimize risk of field failures
  - Withstand expected loads.
- **Validate blade design**
  - Stress and strain
  - Stiffness and deflection
  - Ultimate static strength
  - Design life verification.

Photo by Dave Snowberg, NREL 19513

Blade Failures during Testing

- **Observed failures**
  - Manufacturing defect
  - Bondline
  - Material/design
  - Root hardware.
- **NREL's experience**
  - Effect of defect tests
  - Majority of failures have occurred during fatigue testing.


Photo by Scott Hughes, NREL


Photo by Mike Desmond, NREL


Photo by Scott Hughes, NREL

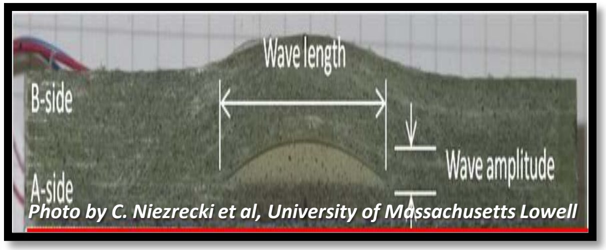

Photo by C. Niezrecki et al, University of Massachusetts Lowell

Flaw and Failure Detection

- **Effect of defect tests**
- **Sensing technologies**

Photo by Scott Hughes, NREL

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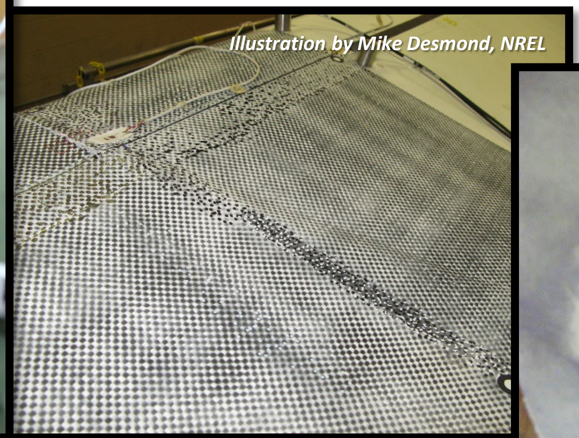

Illustration by Mike Desmond, NREL

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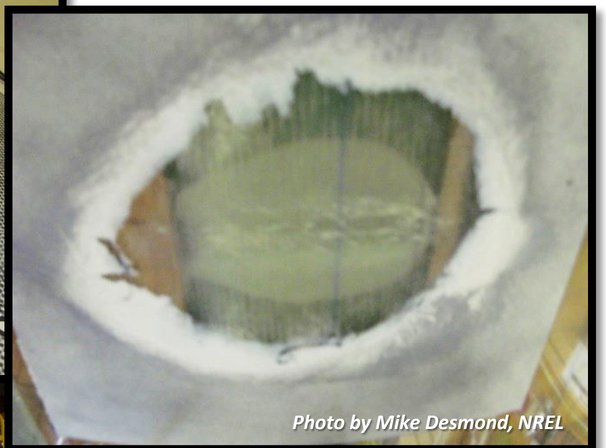

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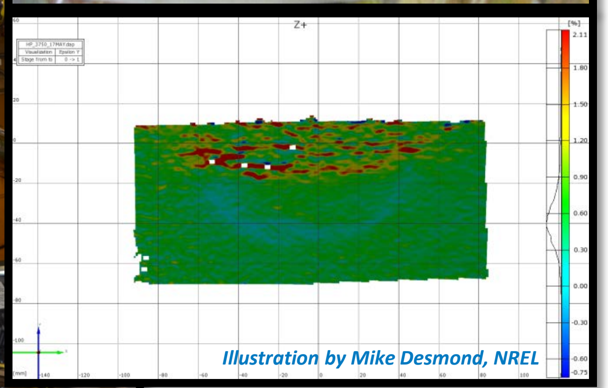


Illustration by Mike Desmond, NREL

Blade Trends and Testing Challenges

- **Longer, lighter blades**
- **Increasingly large deflections**
- **Complex geometries**
  - Prebend
  - Sweep.
- **Innovative materials and manufacturing methods**
- **Component-based blades.**

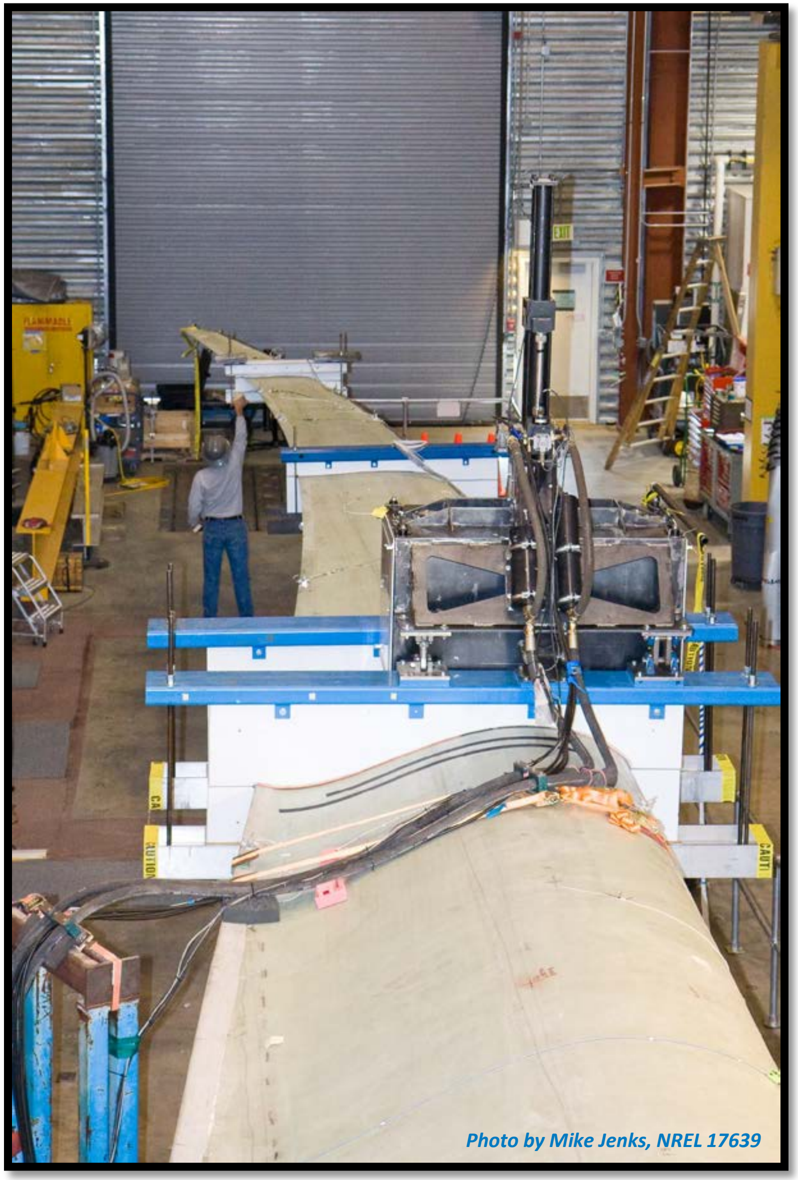
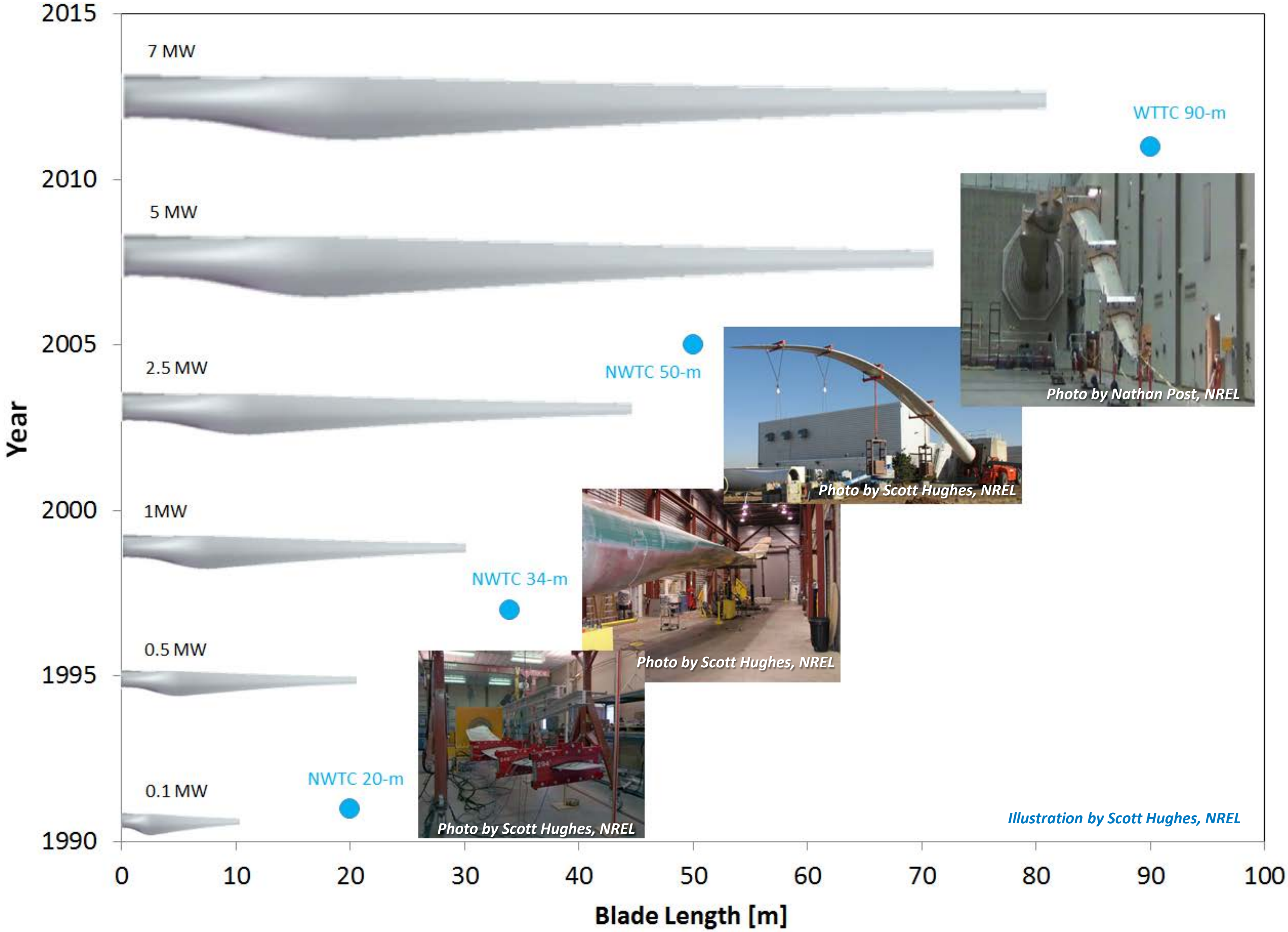


Photo by Mike Jenks, NREL 17639

Test Facility Capability of NWTC and Wind Technology Testing Center (WTTC)



Test Method Development

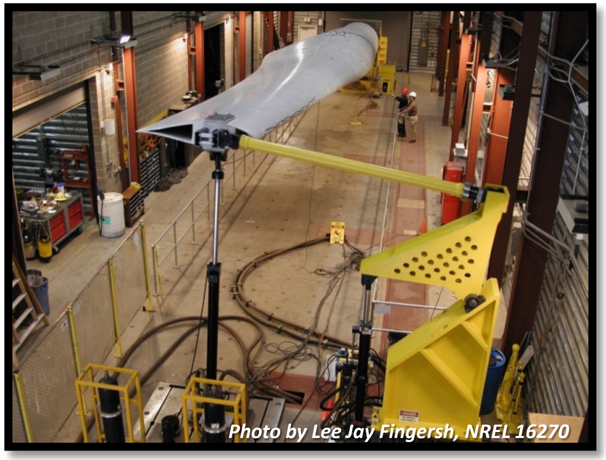
Objectives

- Improve fidelity
- Decrease testing time
- Reduce testing costs.

Photo by Warren Gretz, NREL 12893

Photo by Dave Snowberg, NREL

1990s	2000s	2010s
Normative Methods	Resonant Methods	Biaxial Methods



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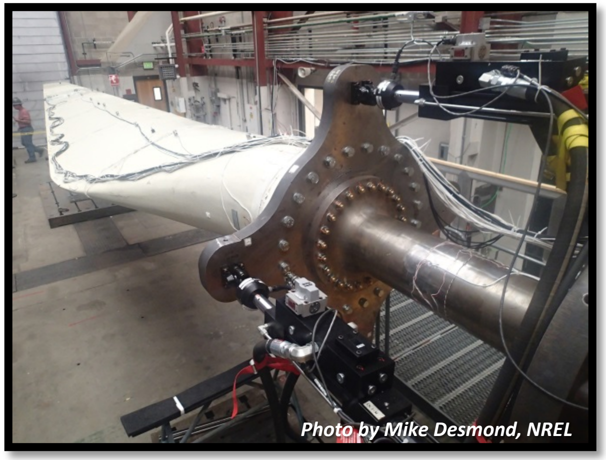

Photo by Mike Desmond, NREL

Commercialized Technologies

- **MTS, MassCEC, and NREL cooperatively developed and commercialized testing hardware for deployment to industry**

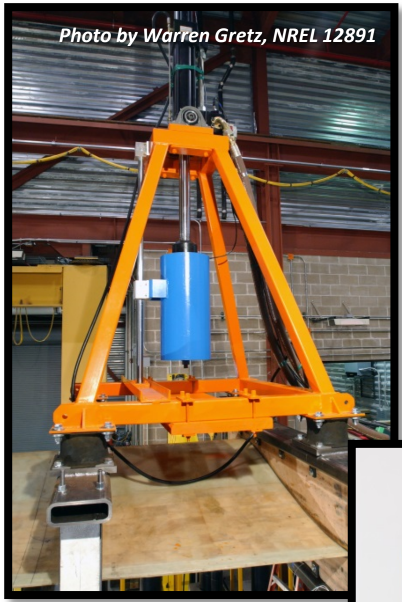

Photo by Warren Gretz, NREL 12891

Prototype resonant excitation method developed and demonstrated at NREL

Commercially available MTS Inertial Resonant Excitation (IREX) hardware

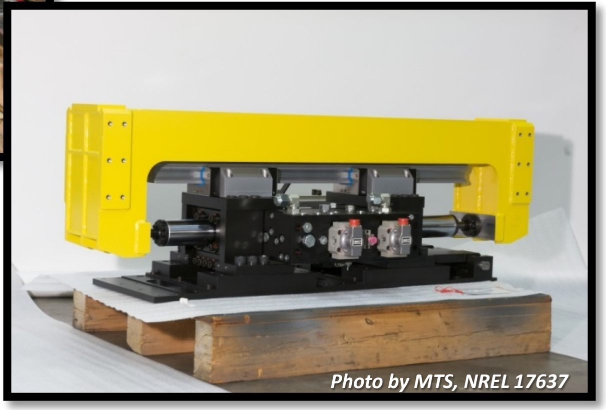

Photo by MTS, NREL 17637

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Commercially available MTS Ground Resonant Excitation (GREX) hardware

Recent Testing Activities

- Biaxial resonant testing
- Biaxial base excitation
- Biaxial forced resonant hybrid.


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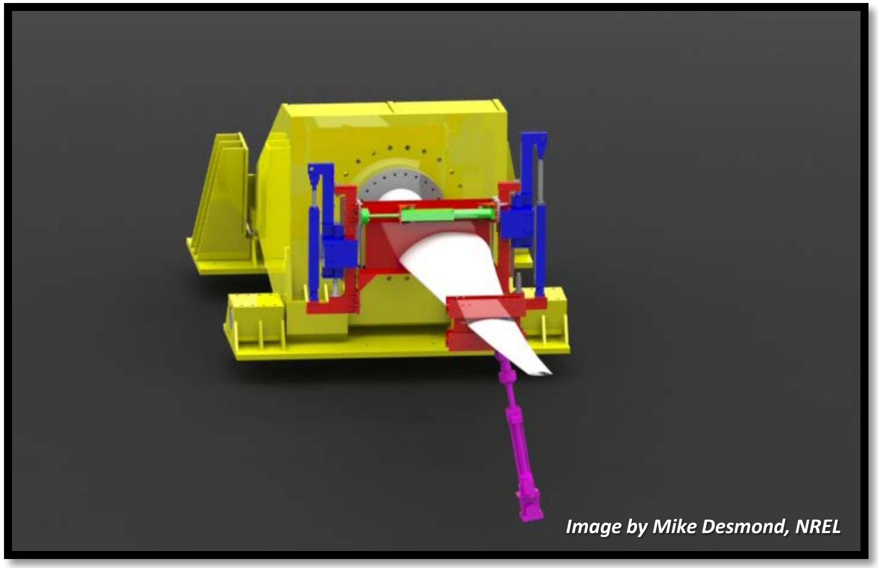
Photo by Dave Snowberg, NREL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Thank You

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